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# RESEARCH MEMORANDUM

for the

Air Materiel Command, U. S. Air Force

## PERFORMANCE OF J33-A-21 and J33-A-23 TURBOJET-ENGINE COMPRESSORS WITH WATER INJECTION

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NATIONAL ADVISORY COMMITTEE
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# PERFORMANCE OF J33-A-21 and J33-A-23 TURBOJET-ENGINE COMPRESSORS WITH WATER INJECTION

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## SUMMARY

As part of the performance investigation of compressors for the J33 turbojet engine, the A-21 model and the A-23 model with a 17- and a 34-blade impeller were operated with water injection at their respective design equivalent speeds of 11,500 and 11,750 rpm. Inlet conditions of pressure of 14 inches of mercury absolute and of ambient temperature correspond to those of the investigation of these models without water injection. The water-air ratio by weight ranged from 0.05 to 0.06.

By the use of water injection, the peak pressure ratio of the A-21 compressor and the A-23 compressor with a 34-blade impeller increased approximately 0.38, whereas that of the A-23 compressor with a 17-blade impeller increased only 0.14. The decrease in maximum efficiency for the three compressors ranged from 0.12 to 0.14. The highest increase in maximum equivalent weight flow of air plus weight flow of water was 10.90 pounds per second obtained with the A-21 compressor. The increase in air weight flow alone was approximately 5.70 pounds per second for the A-21 compressor and the A-23, 17-blade compressor, which exceeded the increase of 3.15 pounds per second for the A-23, 34-blade compressor.

## INTRODUCTION

At the request of the Air Materiel Command, U. S. Air Force, an investigation was conducted at the NACA Lewis laboratory to determine the performance characterisitcs of a series of J33 turbojet-engine compressors. Standard performance data without water injection

for the A-21 model compressor and the A-23 compressor with a 17- and a 34-blade impeller are reported in references 1, 2, and 3, respectively.

The results of an investigation with water injection at the design equivalent speeds of each compressor and inlet pressure of 14 inches of mercury absolute and ambient inlet temperature are presented herein. These conditions are the same as those for operation without water injection and permit direct comparison of results. The water-air ratio by weight ranged from 0.05 to 0.06.

## APPARATUS AND PROCEDURE

Apparatus. - The apparatus and the instrumentation are the same as those described in reference 1 with the following additions for water injection: (1) conventional water-alcohol spray nozzles, (2) standard A.S.M.E. flat-plate orifice to measure water flow, and (3) wattmeter for measuring power input to variable-frequency induction motor.

Procedure. - The model A-21 and A-23 compressors were operated at an inlet pressure of 14 inches of mercury absolute, ambient inlet temperature, and their respective design equivalent speeds of 11,500 and 11,750 rpm. These operating conditions are the same as those used in the investigations without water injection (references 1 to 3) in order to permit direct comparison of data. The water-air ratio by weight ranged from 0.05 to 0.06.

Computations. - The large variation in the compressor-outlet temperatures with water injection made it impossible to determine the actual energy absorbed by the working fluid by thermodynamic methods (reference 4). The actual (not corrected to standard sea-level conditions) power absorbed by the compressor was therefore determined by measuring the power input to the motor and allowing for the losses in the motor, the gear box, and the assembly. The validity of this method was checked by computing the actual energy absorbed by the working fluid from performance data of these three compressors without water injection. The percentage deviation in power is defined as the difference between the horsepower determined by computing the actual energy absorbed by the working fluid and the horsepower determined by measuring the power input to the motor without water injection divided by the horsepower determined by computing the actual energy absorbed by the working fluid. The results obtained by the two methods are presented in figure 1.

The compressor efficiency with water injection is the ratio of the isentropic work, which is found by using the enthalpy rise for an isentropic process (determined by the method presented in reference 4), and the actual work determined by power-input measurements. Throughout this investigation, the humidity of the inlet air with water injection is low and its effect on efficiency is small enough to be neglected.

Precision. - The precision of the measurements is estimated to be within the following limits:

| | |
|---|---|
| Temperature, °F | ±0.5 |
| Pressure, inches mercury absolute | ±0.04 |
| Speed, percent | ±0.3 |
| Air weight flow, percent | ±1.0 |
| Water weight flow, percent | ±1.0 |

From figure 1, a deviation between the actual power absorbed as computed by the two methods is apparent. This deviation is reflected in the efficiency computations and must be considered if absolute accuracy is desired. The computation of efficiency of the A-21 compressor with water injection can be as much as 0.015 too high. The efficiency computation of the A-23, 17-blade and 34-blade compressors can be as much as 0.010 and 0.018 too high, respectively.

## RESULTS AND DISCUSSION

The effect of water injection on the performance of the three compressors is shown in figure 2. The equivalent weight of air flow plus the weight of water flow is termed "total weight flow." Representative changes in the principal variables are given in the following table:

| Compressor | Increase in peak pressure ratio | Decrease in maximum efficiency | Increase in maximum total weight flow | | Increase in total weight flow at surge point | | Increase in maximum air flow | |
|---|---|---|---|---|---|---|---|---|
| | | | (lb/sec) | (percent) | (lb/sec) | (percent) | (lb/sec) | (percent) |
| A-21 | 0.38 | 0.12 | 10.90 | 13.00 | 8.05 | 10.90 | 5.65 | 6.73 |
| A-23 17-blade | .14 | .14 | 10.75 | 12.21 | 13.70 | 16.93 | 5.75 | 6.54 |
| A-23 34-blade | .37 | .13 | 7.90 | 8.66 | 7.20 | 8.80 | 3.15 | 3.43 |

The large decrease in efficiency with water injection reflects the effects of both the aerodynamic compression process and the evaporative cooling. Because of the change in velocities of the mixture through the compressor with water injection, a compressor designed for optimum performance without water injection does not necessarily operate at peak performance with water injection. With water injection the compressor is also charged for all losses that might result from improper methods of injection. The increase in pressure ratio results from an effective increase in the compressor speed due to the cooling of the air by the water injected, the magnitude of the pressure ratio increase being dependent on the efficiency of the process. The increase in equivalent weight flow of air alone is due to the increase in density resulting from the cooling of the air by the water injected and from the increase in compressor pressure ratio.

The performance of the three compressors with water injection is compared in figure 3. The peak pressure ratio of the A-23, 17-blade compressor and the A-21 compressor was 0.32 and 0.47 lower, respectively, than that of the A-23, 34-blade compressor. The maximum efficiency of the A-23, 17- and 34-blade compressors are approximately equal and the efficiency of the A-21 compressor is approximately 0.04 lower than that of the A-23, 34-blade compressor.

The variation of specific power required with and without water injection where the specific power is defined as the actual horsepower required divided by the actual total weight flow is shown in figure 4. With water injection, the specific power increased 3 to 7 percent for the A-21 compressor and 1 to 2 percent for the A-23, 34-blade compressor. The specific power decreased slightly for the A-23, 17-blade compressor. The change in specific power with water injection is apparently the result of changes in the flow characteristics through the impeller passages.

## SUMMARY OF RESULTS

An investigation of the performance of the J33-A-21 and J33-A-23 turbojet-engine compressors with water injection produced the following results:

1. The peak pressure ratio of the A-21 compressor and the A-23 compressor with 34-blade impeller increased approximately 0.38, whereas for the A-23 compressor with 17-blade impeller the increase was only 0.14.

2. Water injection decreased the maximum efficiency for the three compressors 0.12 to 0.14.

3. The increase in maximum total weight flow ranged from 7.90 pounds per second for the A-23 compressor with a 34-blade impeller to 10.90 pounds per second for the A-21 compressor. The increase in maximum air flow alone ranged from 3.15 pounds per second for the A-23 compressor with 34-blade impeller to approximately 5.70 pounds per second for the A-21 compressor and the A-23, 17-blade compressor.

4. With water injection the specific power increased 3 to 7 percent for the A-21 compressor and 1 to 2 percent for the A-23 compressor with 34-blade impeller.

Lewis Flight Propulsion Laboratory,
National Advisory Committee for Aeronautics,
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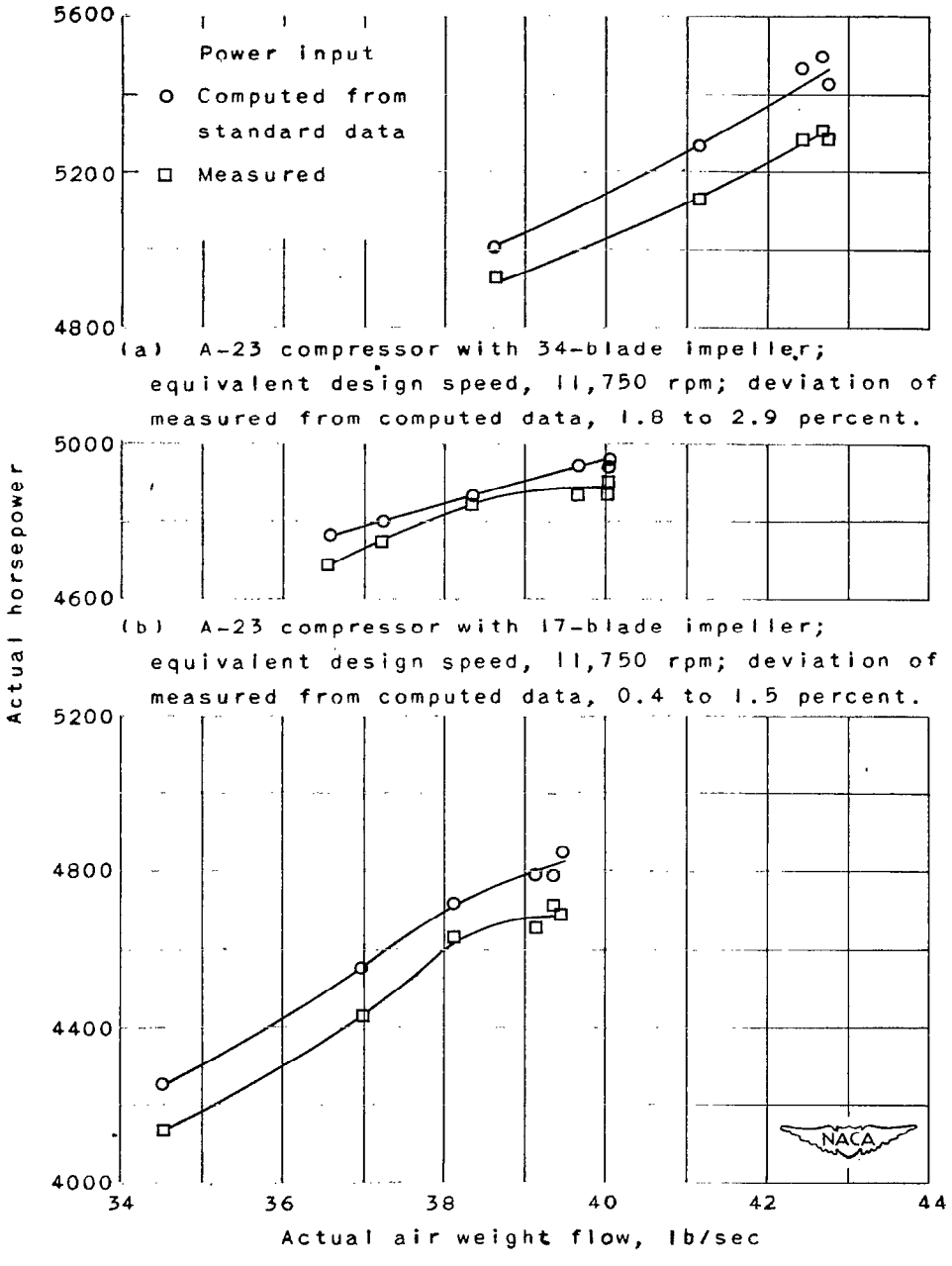
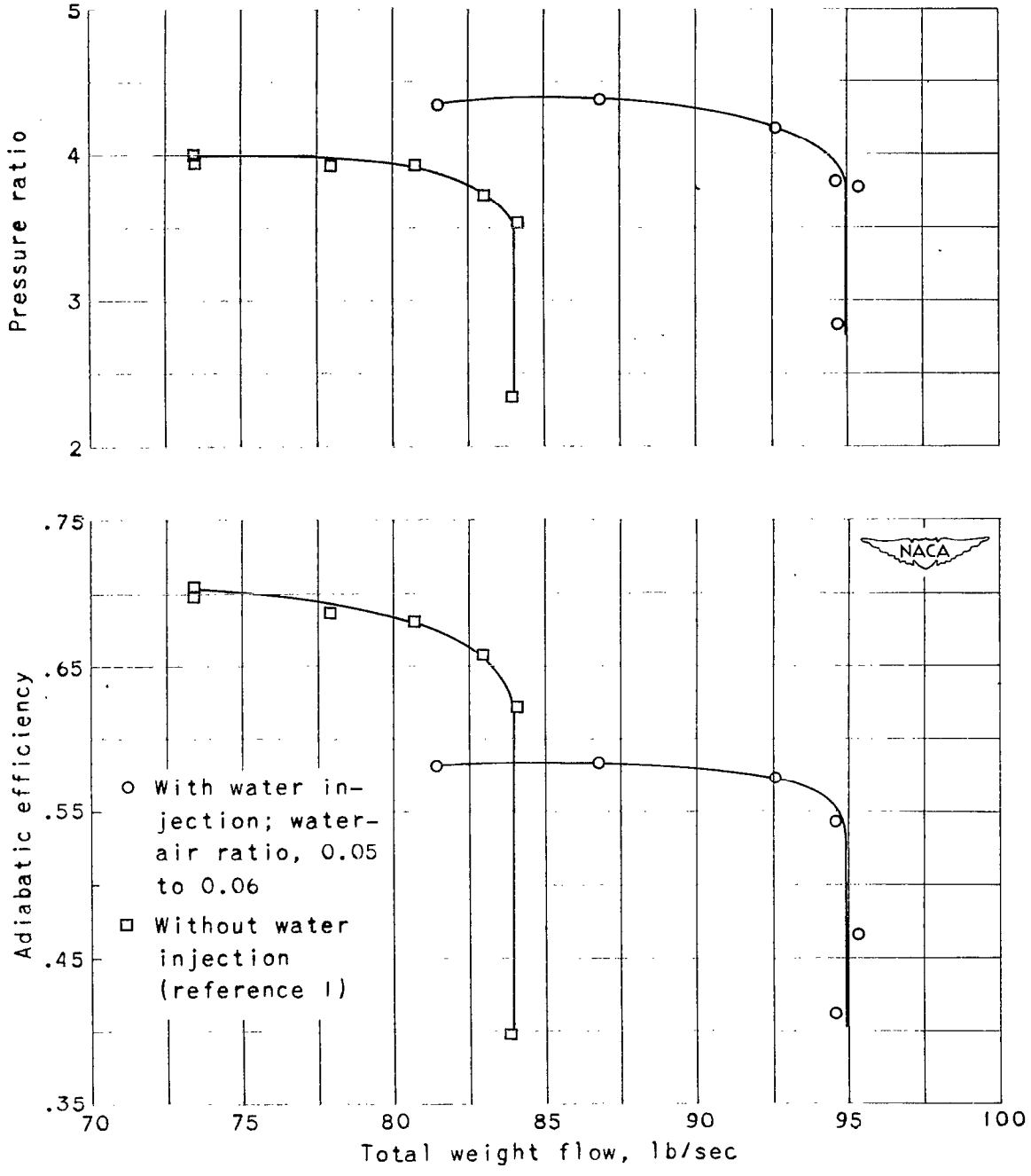



(a) A-23 compressor with 34-blade impeller; equivalent design speed, 11,750 rpm; deviation of measured from computed data, 1.8 to 2.9 percent.

(b) A-23 compressor with 17-blade impeller; equivalent design speed, 11,750 rpm; deviation of measured from computed data, 0.4 to 1.5 percent.

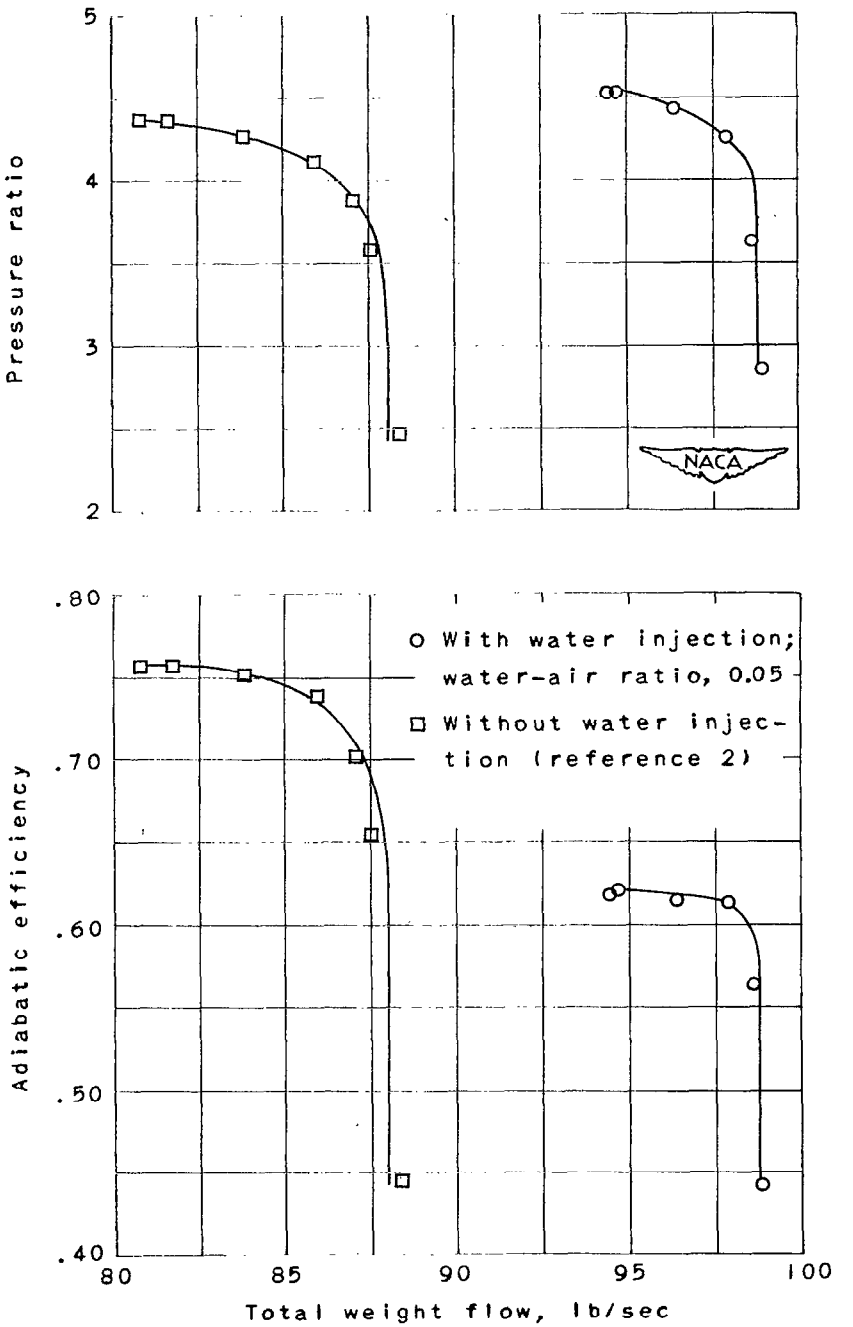
(c) A-21 compressor; equivalent design speed, 11,500 rpm; deviation of measured from computed data, 1.9 to 2.7 percent.

Figure 1. - Power determination of J33 compressors without water injection at inlet pressure of 14 inches of mercury absolute and ambient inlet temperature.



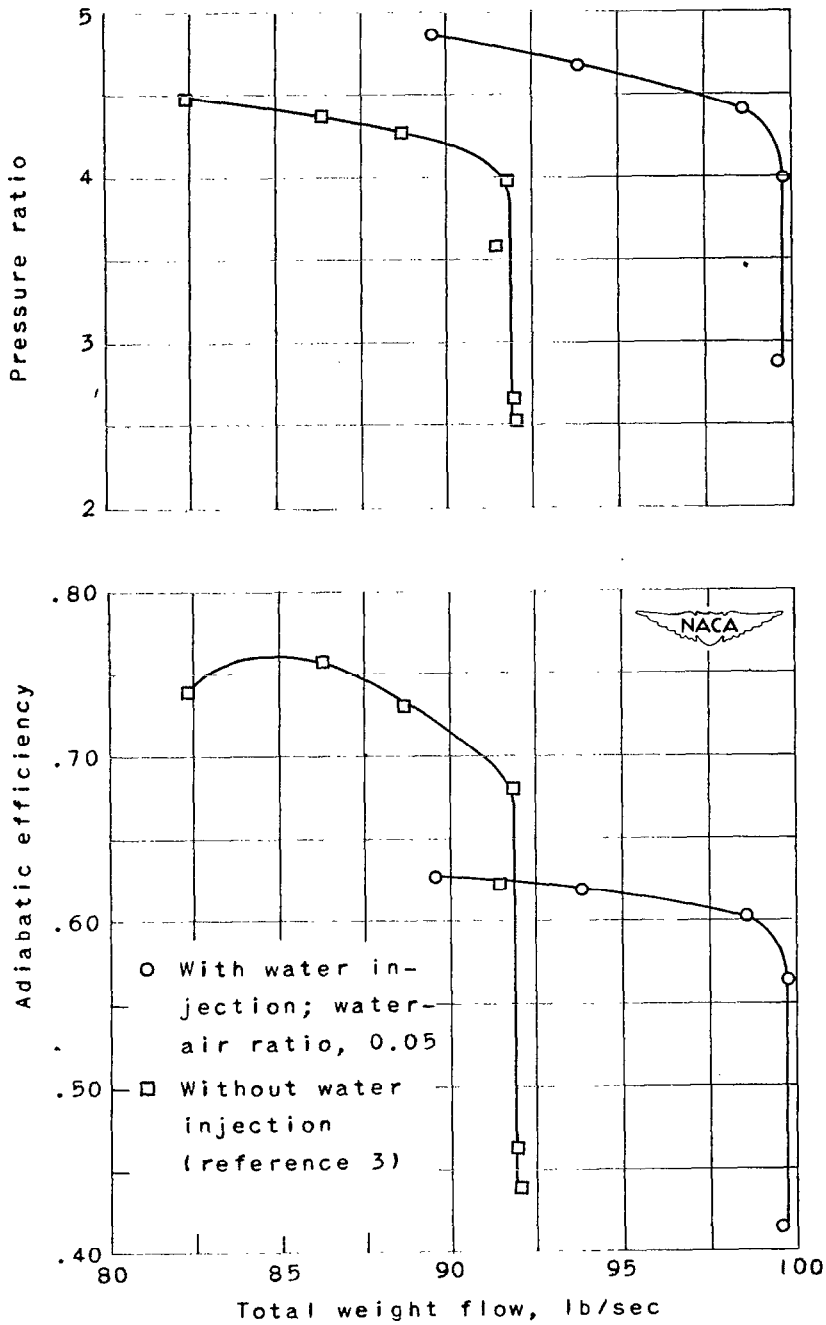

(a) A-21 compressor; equivalent design speed, 11,500 rpm.

Figure 2. - Performance of J33 compressors with and without water injection.




(b) A-23 compressor with 17-blade impeller; equivalent design speed, 11,750 rpm.

Figure 2. - Continued. Performance of J33 compressors with and without water injection.




(c) A-23 compressor with 34-blade impeller; equivalent design speed, 11,750 rpm.

Figure 2. - Concluded. Performance of J33 compressors with and without water injection.

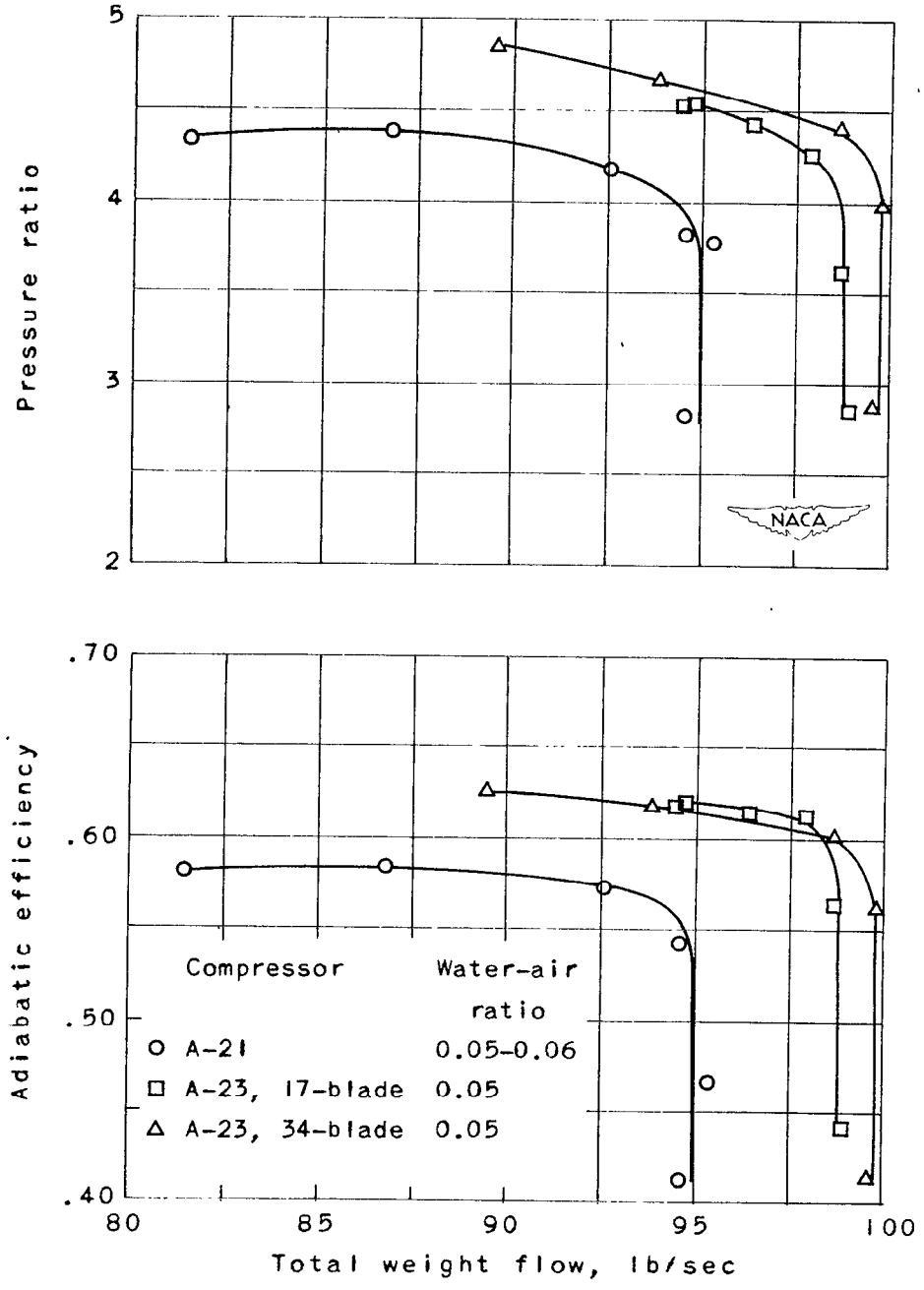



Figure 3. - Performance of J33 compressors with water injection at equivalent design speeds.

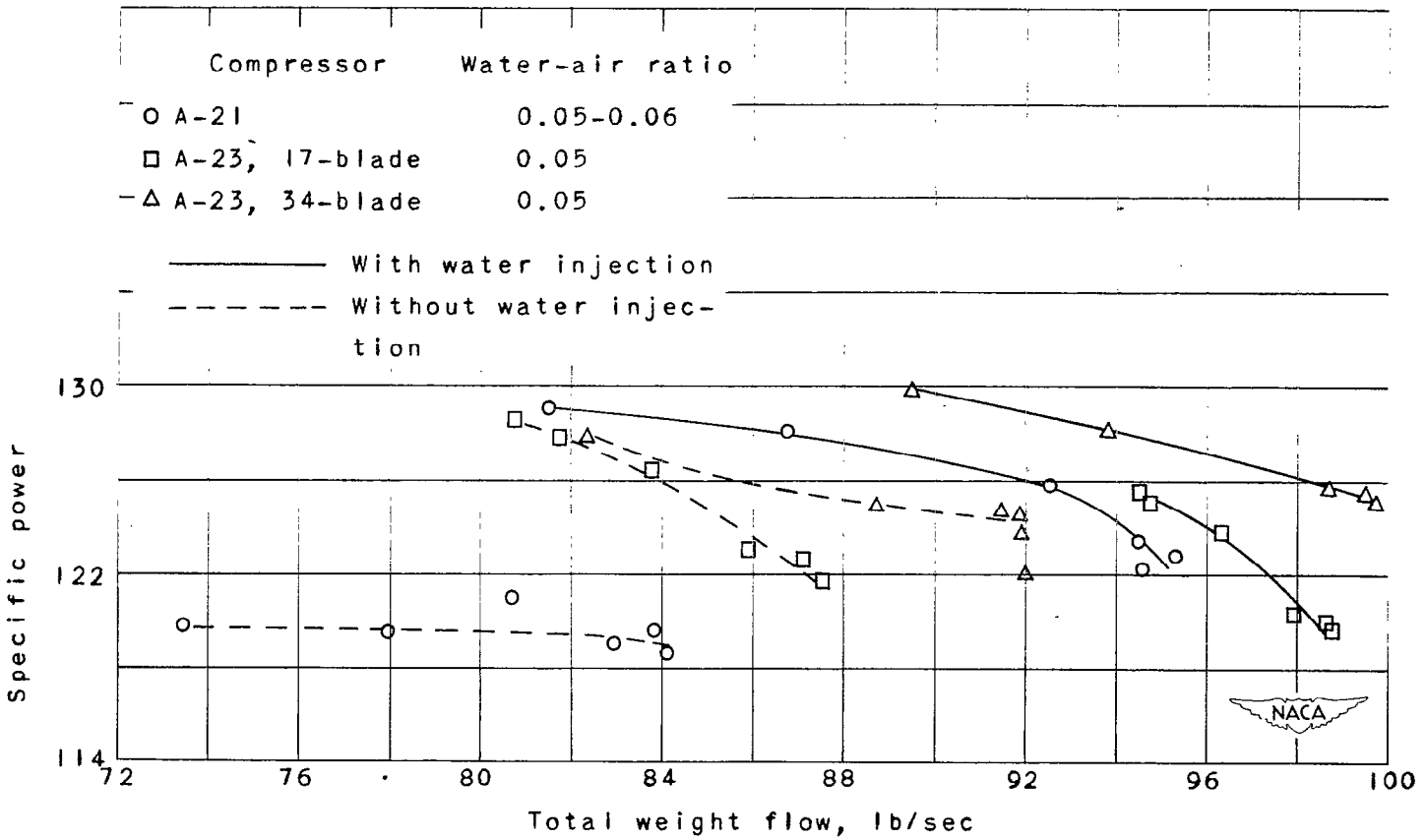



Figure 4. - Specific power absorbed by compressor with and without water injection at inlet pressure of 14 inches of mercury absolute and ambient inlet temperature.